Source Zone Remediation Using Biodegradation

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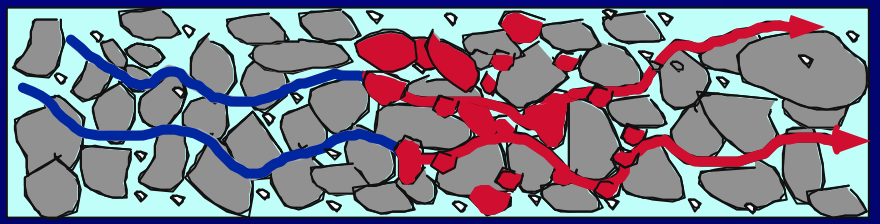
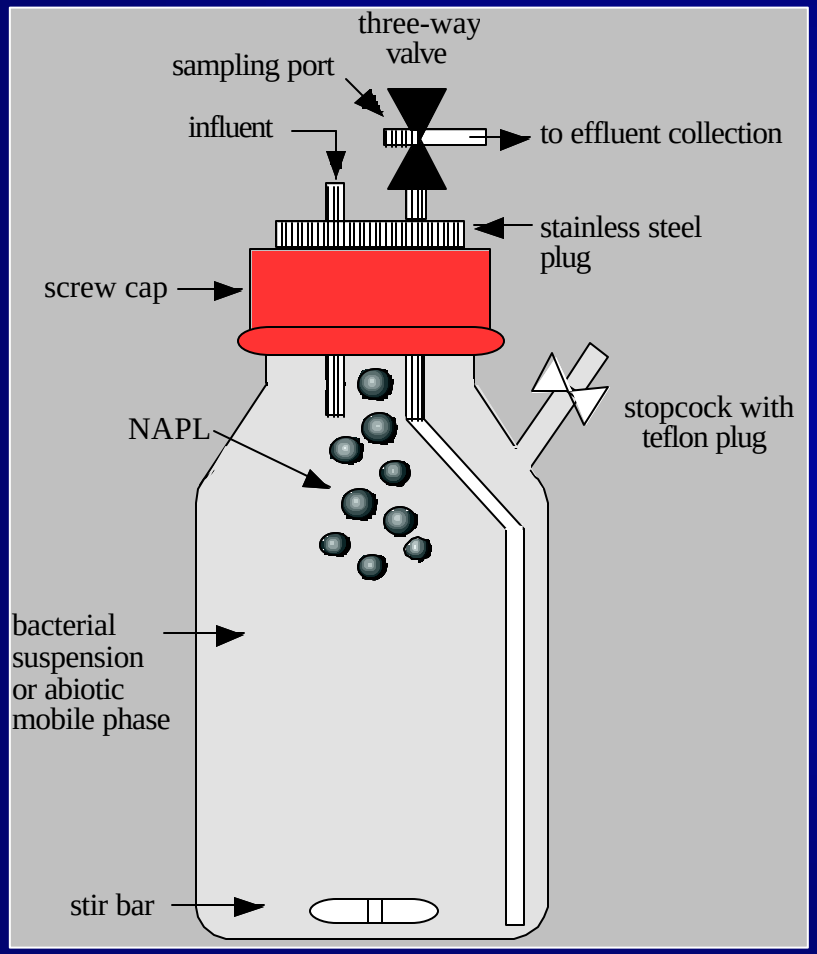
Can You Bioremediate DNAPL Source Zones?

BACKGROUND

- Most chlorinated solvent sites have DNAPL
- DNAPL is rarely seen
- Key issues:
  - cost of substrate
  - how to deliver
  - does mass transfer limitations mean failure?



NAPL Longevity Studies



- Add PCE in tridecane
- Feed formate as E.D.
- Monitor PCE longevity in presence and absence of dechlorination
- Evaluate the impact on “wash out” flux and compositional changes

Summary of Results

- PCE longevity in biotic systems was 14x faster than abiotic systems

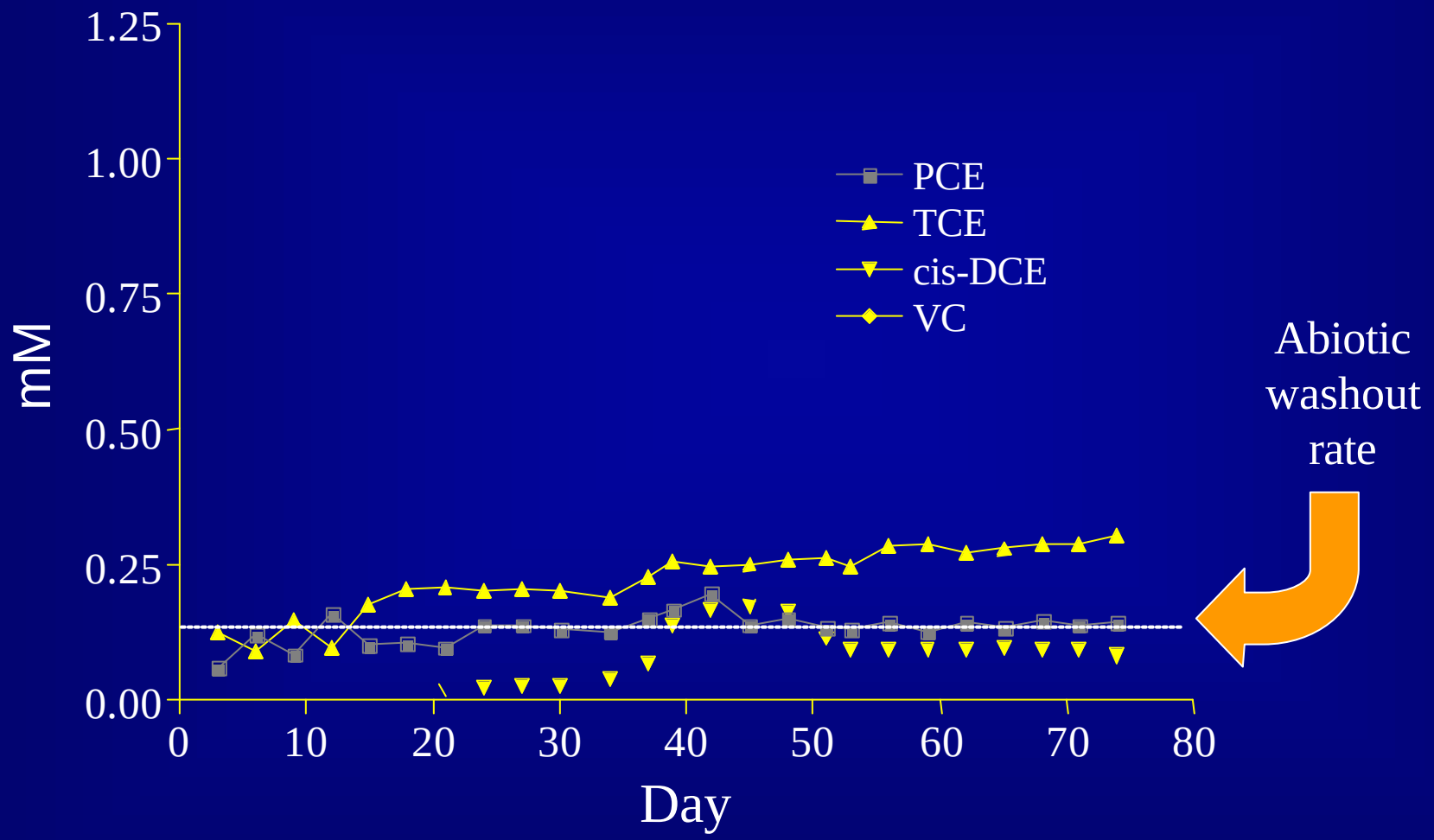
- Total chlorinated ethenes longevity in biotic systems was 8x faster than abiotic systems

Carr, Garg, and Hughes (2000) *Environ. Sci. Technol*. *34*(6), 1088-1094

Column Studies

- Residual PCE-Tridecane NAPL developed in 3 columns (~ 15%)
- Inoculated with culture and fed pyruvate at 25 mM, 100 mM, and 250 mM
- HRT = 3 days
- Monitored for effluent chlorinated ethenes, methane production, and volatile acids
- Cryogeneic dissection after 80 days

Low Electron Donor



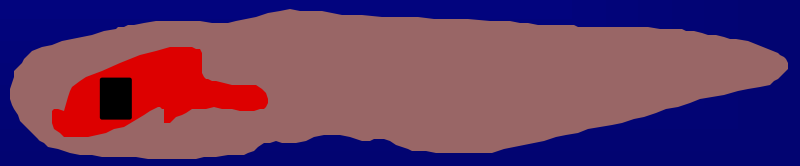
Findings

- All columns fermented pyruvate to acetate and propionate, no methane production
- PCE removal was **16x faster** in biotic column fed 100mM pyruvate than dissolution alone
- Total ethene removal was **5.0x to 6.5x greater** than dissolution alone
- Effluent chlorinated solvent concentrations may be poor indicators of longevity

Cost of Substrate

Template Site Economic Analysis (Harkness, 2000)

- **Source zone 25m x 30 m x 19 m (0.2 acres)**
- **Source contains 2725 kg PCE (10 drums)**
- **NAPL saturation = 0.0005 (0.05 % of pore vol.)**



Cost of Substrate

Key Assumptions:

- **Need Donor:PCE ratio = 35:1**
- **Donor is $0.77 per pound**

Case 2: Batch Feed System

- **$130,000 for donor (15% of total system cost)**

Cost of Substrate

DiStefano and Baral, 2000:

- **Donor costs are $0.02 to $0.12 per pound**
- **Ratio of donor:PCE ranges from 5x to 20x**
- **Cost per pound of PCE: $ 0.04 to $ 0.85**

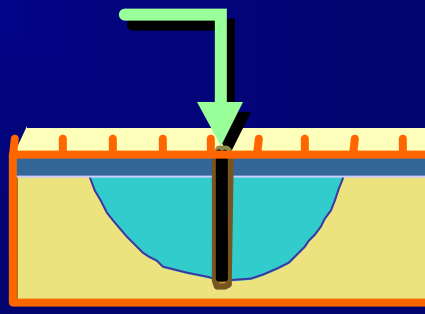
- **$1200 for donor (assuming $0.20 per lb of PCE)**

Delivery Systems

For source treatment, radius of influence is important

- **Dissolved substrates, gas foam: 15 - 30 ft**
- **Semi-solids, gas: 10 to 15 ft**
- **How many injection points?**

Radius (ft)	Wells per Acre
10	430
15	200
30	50

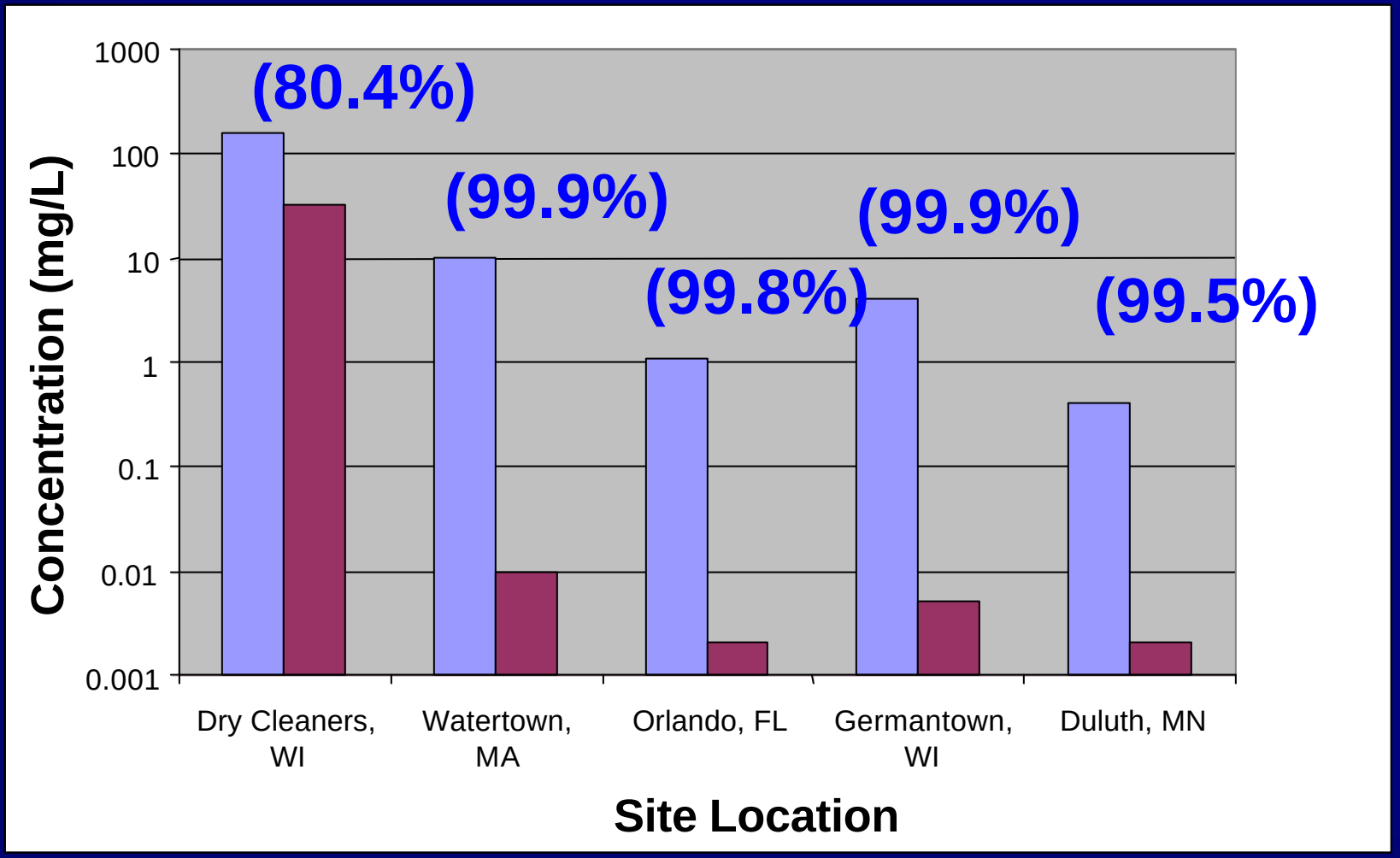


Reported Cost Information for Bioremediation (preliminary)

SITE	TREATMENT	TOTAL COST	TREATMENT AREA	$ / ACRE
Watertown, MA	HRC	$ 50 K	0.01 acres	$ 545 K
Orlando, FL	HRC	$ 127 K	0.74 acres	$ 384 K
Duluth, MN	HRC	$ 20 K	0.05 acres	$ 436 K
Industrial Site, NJ	HRC	$ 15 K	0.03 acres	$ 594 K
Largo, FL	Benzoate, lactate, and methanol	$ 400 K	0.05 acres	$ 2500 K
Williamsport, PA	Molasses	$ 145 K	1.42 acres	$ 190 K
Idaho Falls, ID	Sodium lactate	$ 2,360 K	0.72 acres	$ 3280 K
Houston, TX	Methanol	$ 700 K	3.33 acres	$ 210 K

Average Cost ~ $ 1,000,000 per acre

Reported Decrease in Concentration (mg/L) from SERDP Database

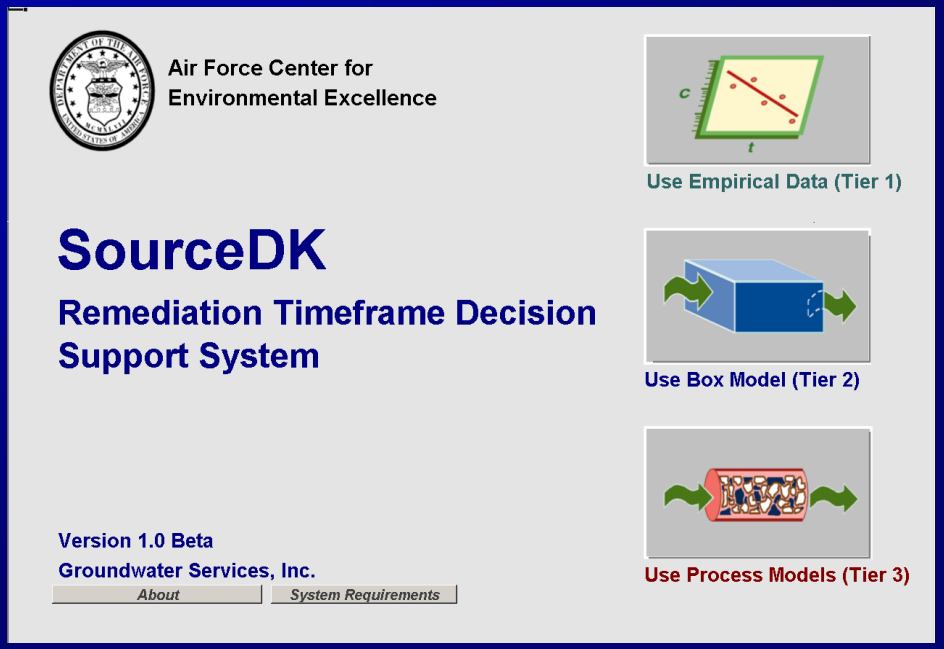


Note: Numbers in ( ) represent the percent reduction (%) in concentration

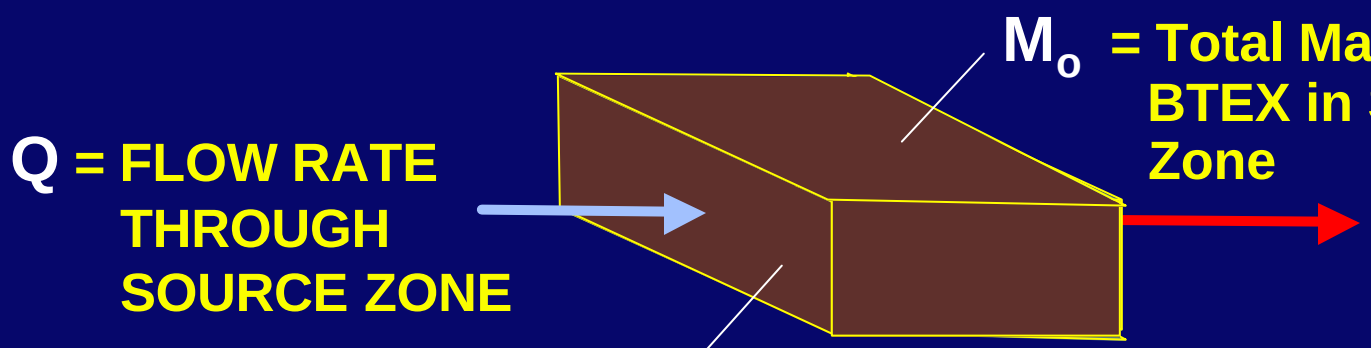
Can You Bioremediate DNAPL Source Zones?

Mass Transfer Issues - Modeling Analysis

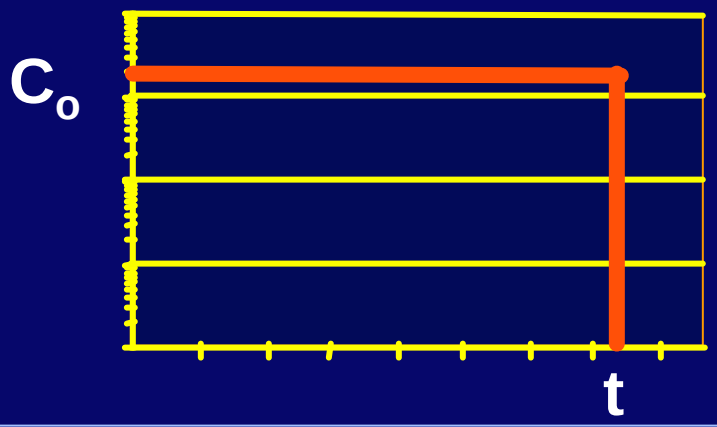
- Modeled Source Decay with SourceDK software
- AFCEE Product in Review



Approach: Assume Source Zone Is a Box



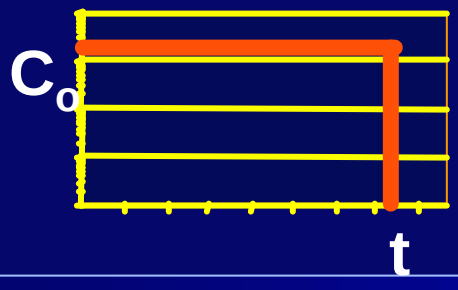
IF CONSTANT SOURCE CONCENTRATION:



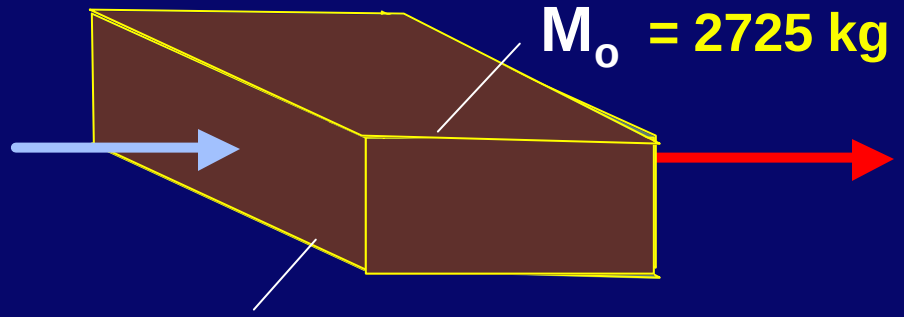
$$t = \frac{M_o}{Q \; C_o}$$

Use Template Site.

Assume Step Function



Q = 2,200,000 L/yr



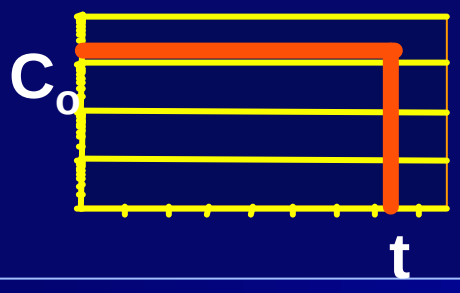
C_o = 10 mg/L BASE CASE

No Biodeg:

$$t = \frac{2725}{(2.2 \times 10^{6})\ (10 \times 10^{-6})} = 124 \text{ yrs}$$

Use Template Site.

Assume donor increases rate by factor of 10x:



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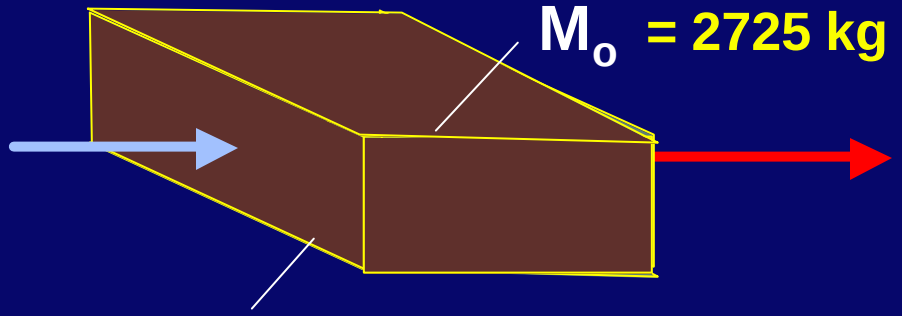


M_o = 2725 kg

C_o = 10 mg/L BASE CASE

$C_{EFFECTIVE}$ = 100 mg/L WITH DONOR

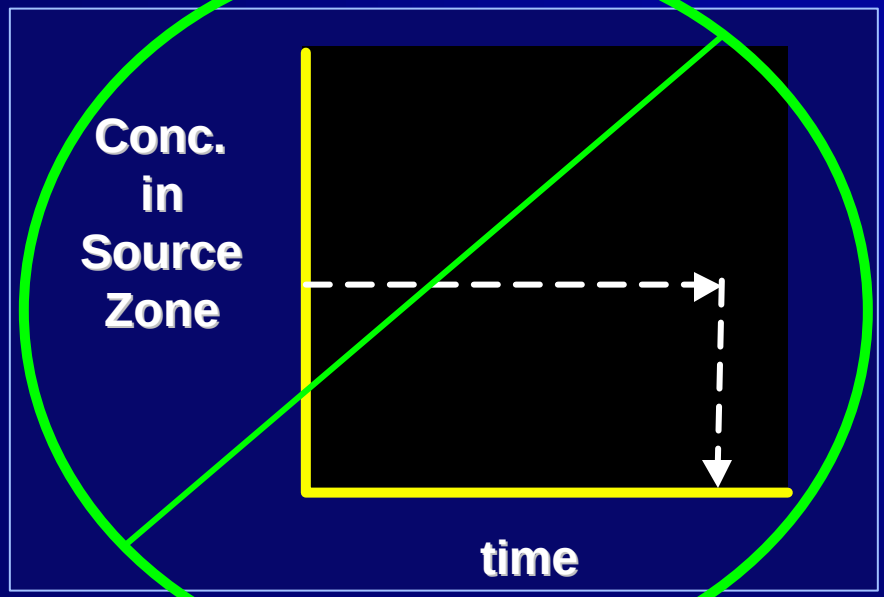
No Biodeg: $t = \frac{2725}{(2.2 \times 10^{6})\ (10 \times 10^{-6})} = 124$ yrs

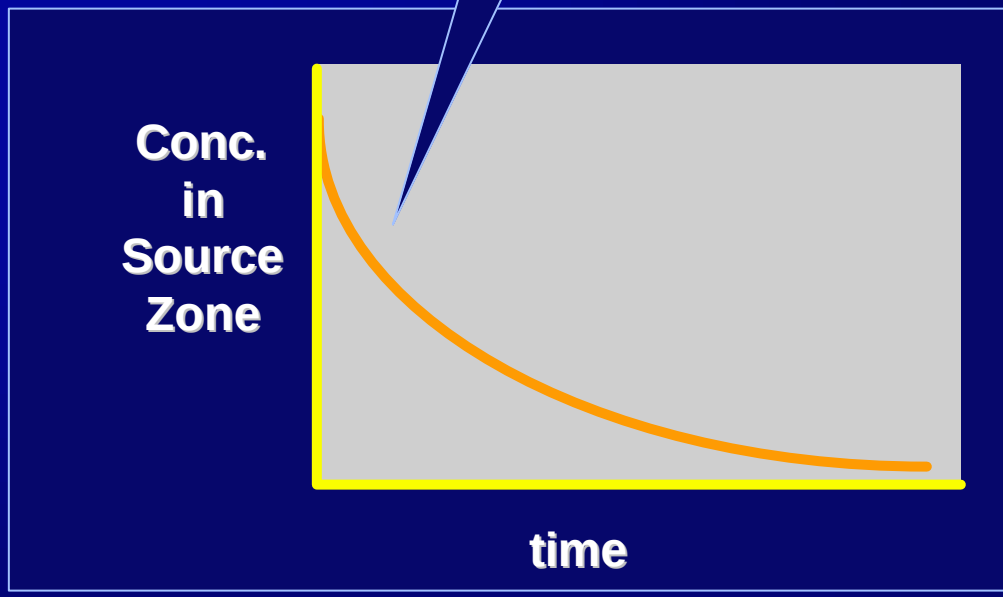
With Biodeg: $t = \frac{2725}{(2.2 \times 10^{6})\ (100 \times 10^{-6})} = 12$ yrs

Better Approximation: Conc. Declines With Tail

First Order Decay Model

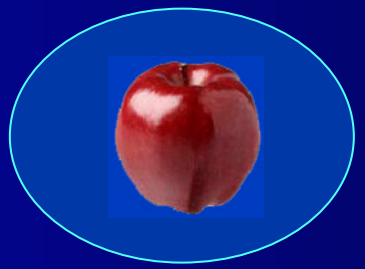
$$C_t = C_o \; e^{(-k_s t)}$$



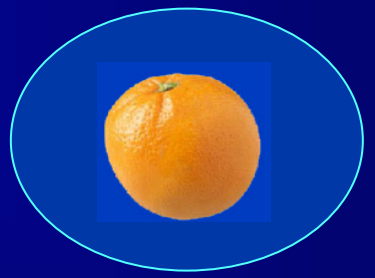


Two Different Types of Rate Constants

Lambda represents how quickly dissolved organics are biodegraded (c vs. x)



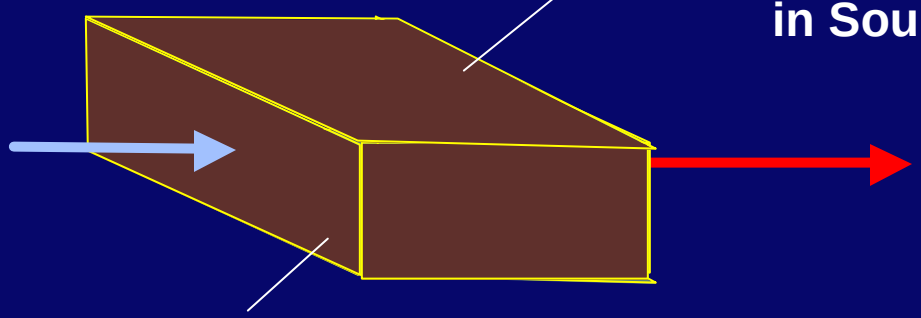
k_s represents how quickly source is being dissolved (half-life in years) (c vs. t)



Source: Newell, Rifai, and Wilson, 2003

Example Assuming Declining Source Conc.

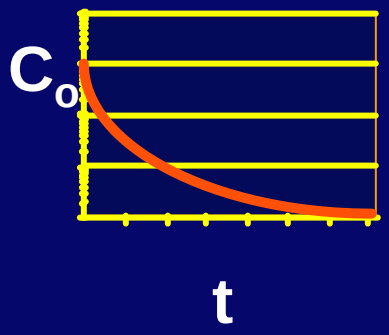
Q = FLOW RATE THROUGH SOURCE ZONE



M_o = Total Mass of BTEX in Source Zone

C_o = Concentration in Source Zone at Time = 0

IF DECLINING SOURCE CONCENTRATION:



$$k_s = \frac{Q \ C_o}{M_o}$$

$$C_t = C_o \bullet e^{-ks\ t}$$

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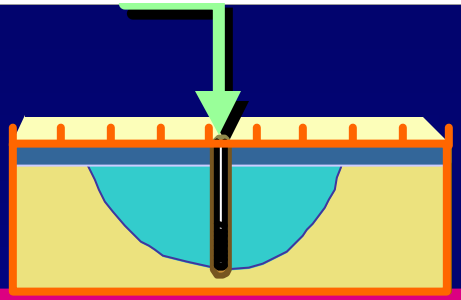
Rate Analysis



Apply SourceDK model to Template Site

Assume no biodegradation

k_s (per year)	Time for 99% Reduction in C
0.008	>500 years

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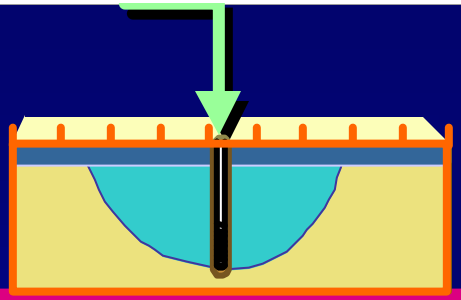
Rate Analysis



Can combine k_s and lambda

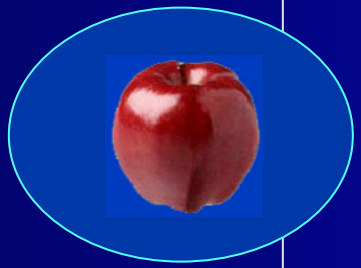
High lambda (caused by donor addition) will reduce k_s

SourceDK allows users to see how biodeg affects source lifetime

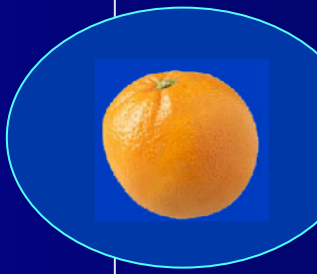
Lamba (per yr)	k_s (per year)	Time for 99% Reduction in C
1	0.03	176 years
10	0.2	24 years
100	2	3 years

Can You Bioremediate DNAPL Source Zones?

Are These Rates Reasonable?



	Lamba (per yr)	k_s (per year)
	1	0.02
	10	0.2
	100	2
Reported Rates	70 - 200 *(SERDP for H_2 addition)*	0.5 - 5 *(Aziz et al, 2000 for typical MNA sites)*



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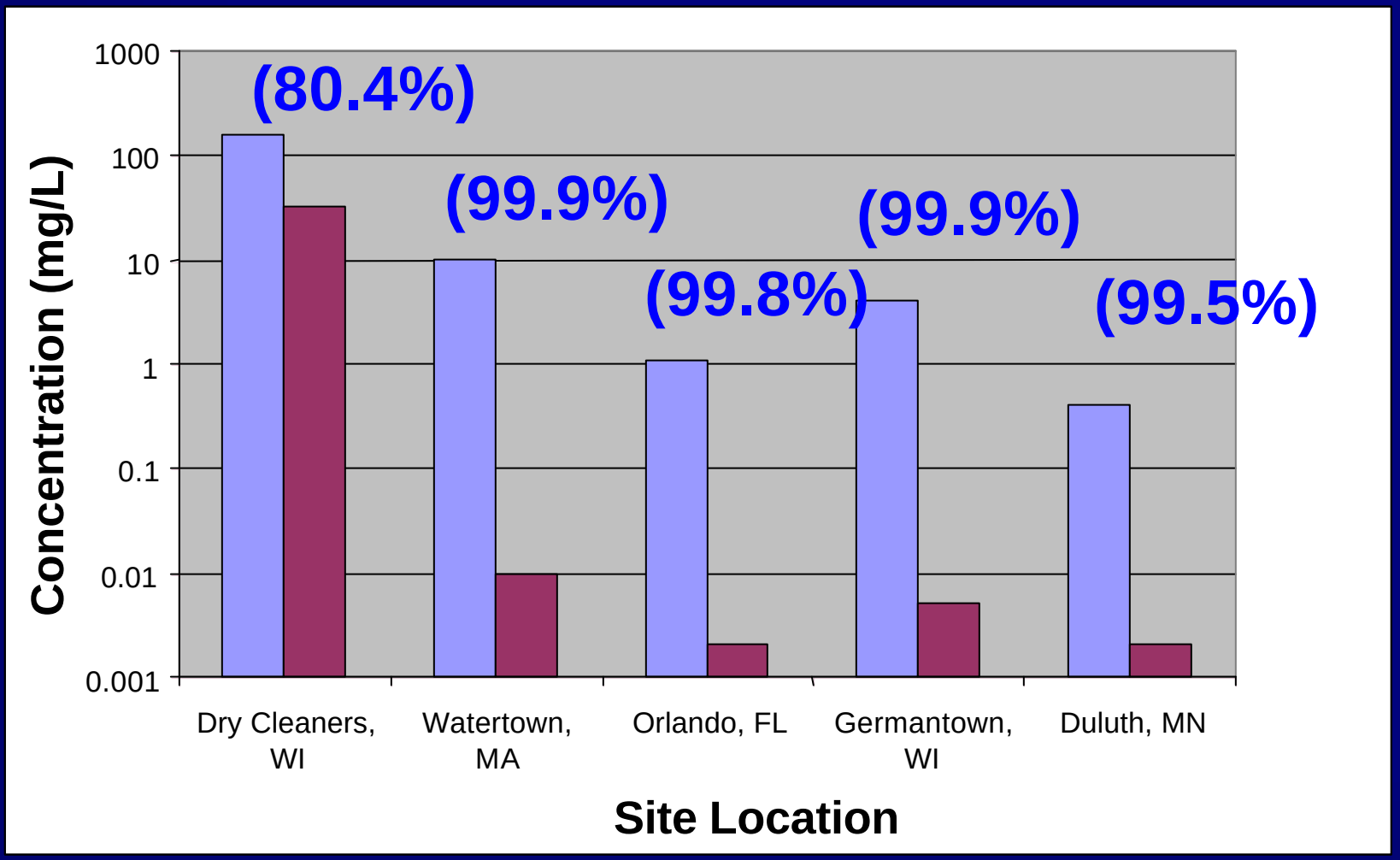
Are These Rates **Reasonable?**

It is reasonable to expect that high source decay rates can be achieved at source bioremediation sites.

Reported Decrease in Concentration (mg/L) from SERDP Database



Note: Numbers in ( ) represent the percent reduction (%) in concentration

CONCLUSION

- Cost data suggests donor cost relatively small
- Cost of delivery system more important
- Rate data from lab, models indicates that bioremediation is feasible for treating source zones in some source settings
- Literature data shows some successes
- Cost vs. containment key issue